N87-16431

MODULE ENCAPSULATION TECHNOLOGY

SPRINGBORN LABORATORIES

P. Willis

Phase I

IDENTIFY AND DEVELOP LOW COST
MODULE ENCAPSULATION MATERIALS

- POTTANTS
- COVER FILMS
- SUBSTRATES
- ADHESIVES/PRIMERS
- ANTI-SOILING TREATMENTS

Phase II

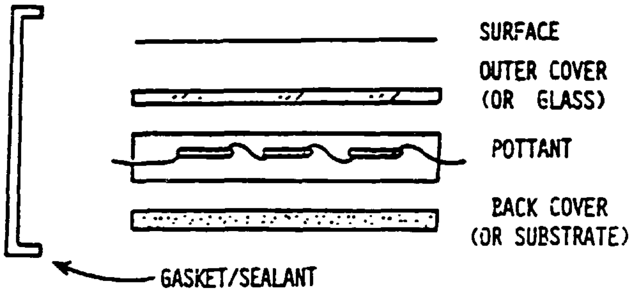
TASK 1: MATERIALS RELIABILITY

- AGING AND LIFE ASSESSMENT
- ADVANCED STABILIZERS
- ADHESIVE BOND DURABILITY
- HUMIDITY SENSITIVITY
- ELECTRICAL ISOLATION

TASK 2: PROCESS SENSITIVITY

- INTERRELATIONSHIPS OF
  - FORMULATION VARIABLES
  - PROCESS VARIABLES
- IDENTIFY FAILURE MODES
- INDUSTRIAL GUIDEANCE

Module Components



CURRENT EMPHASIS ON MATERIALS AND MODULE PERFORMANCE CHARACTERISTICS

- DETERMINE CURRENT LEVEL OF PERFORMANCE
- ENHANCE PERFORMANCE (E.G. REFORMULATION)
- SERVICE LIFE PROGNOSIS

PERFORMANCE CRITERIA

- ENVIRONMENTAL DEGRADATION
- MAXIMUM SERVICE TEMPERATURE
- ADHESIVE BOND DURABILITY
- ELECTRICAL INSULATION DURABILITY
- HYDROLYTIC (WATER) STABILITY
- WHAT ARE DOMINANT TYPES OF FAILURE ?
- WHERE IS STABILIZATION NEEDED ?

Accelerated Aging Test Program

CONDITIONS USED INITIALLY

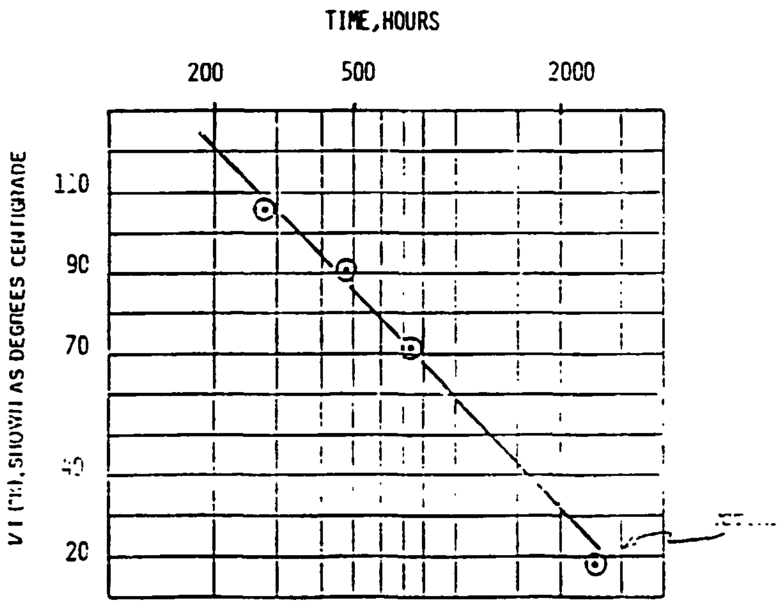
METHOD	DEFICIENCIES
• THERMAL (AIR OVEN)	• UNNATURAL LIGHT
• RS/4 50°C	• NO " WEATHER "
• RS/4 WET SPRAY	• NO PREDICTIVE METHODS
• RS/4 85°C	• LONG EXPOSURE TIMES

OUTDOOR PHOTOTHERMAL AGING REACTORS
(OPTAR)

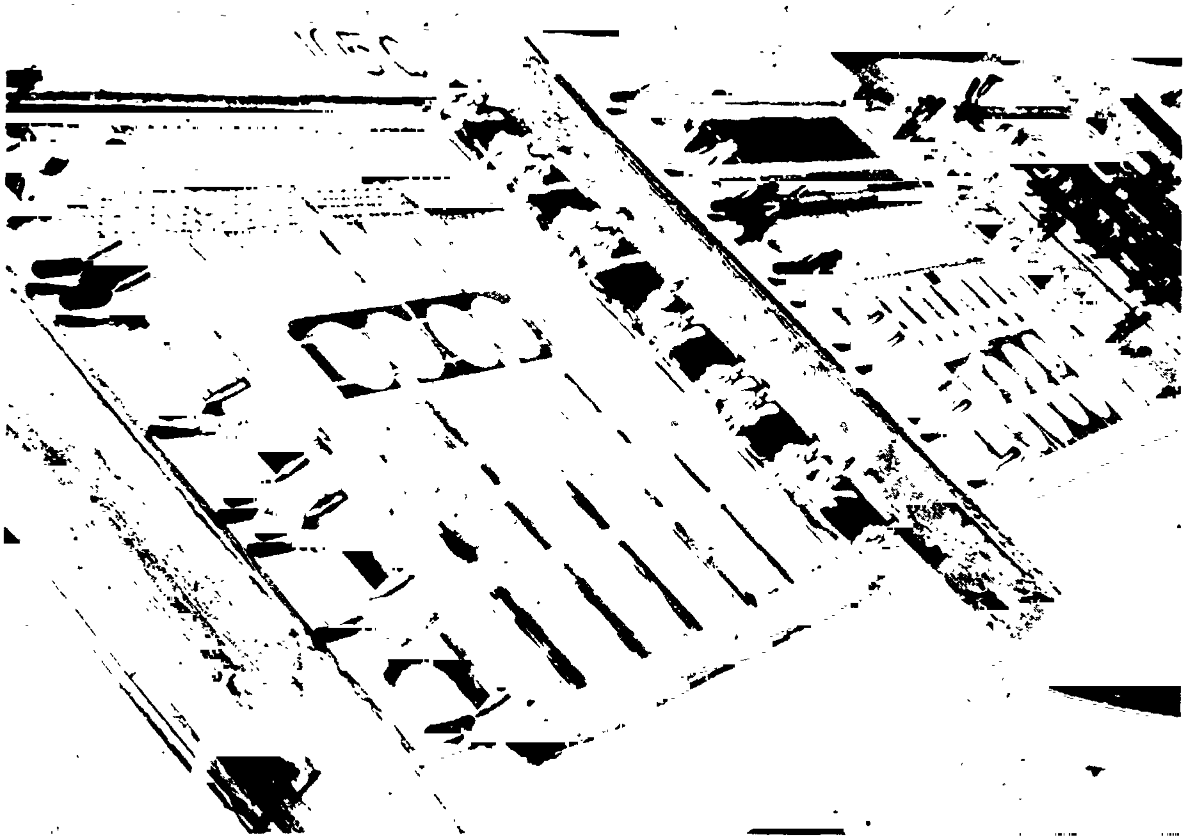
- USE NATURAL SUNLIGHT, AVOIDS SPECTRAL DISTRIBUTION PROBLEMS WITH ARTIFICIAL LIGHT SOURCES
- USE TEMPERATURE TO ACCELERATE THE PHOTO-THERMAL REACTION
- INCLUDES DARK CYCLE REACTIONS
- INCLUDES DEW / RAIN EXTRACTION
- INTENDED PRIMARILY FOR MODULE EXPOSURE
- EXTRAPOLATE EFFECTS TO LOWER TEMPERATURES

Accelerated Aging

- USEFUL FOR EVALUATING CANDIDATE FORMULATIONS - COMPARISON
- WHOLE MODULES UNDER EXPOSURE
- DETERMINE UPPER LEVEL SERVICE TEMPERATURES
- MODELLING:
  - TIME TO ONSET OF DEGRADATION (INDUCTION PERIOD, t_i) EXAMPLE: POLYPROPYLENE
  - ARRHENIUS: LOG t_i vs. 1/K°
  - PREDICT SERVICE LIFE BY EXTRAPOLATION TO LOWER TEMPERATURES

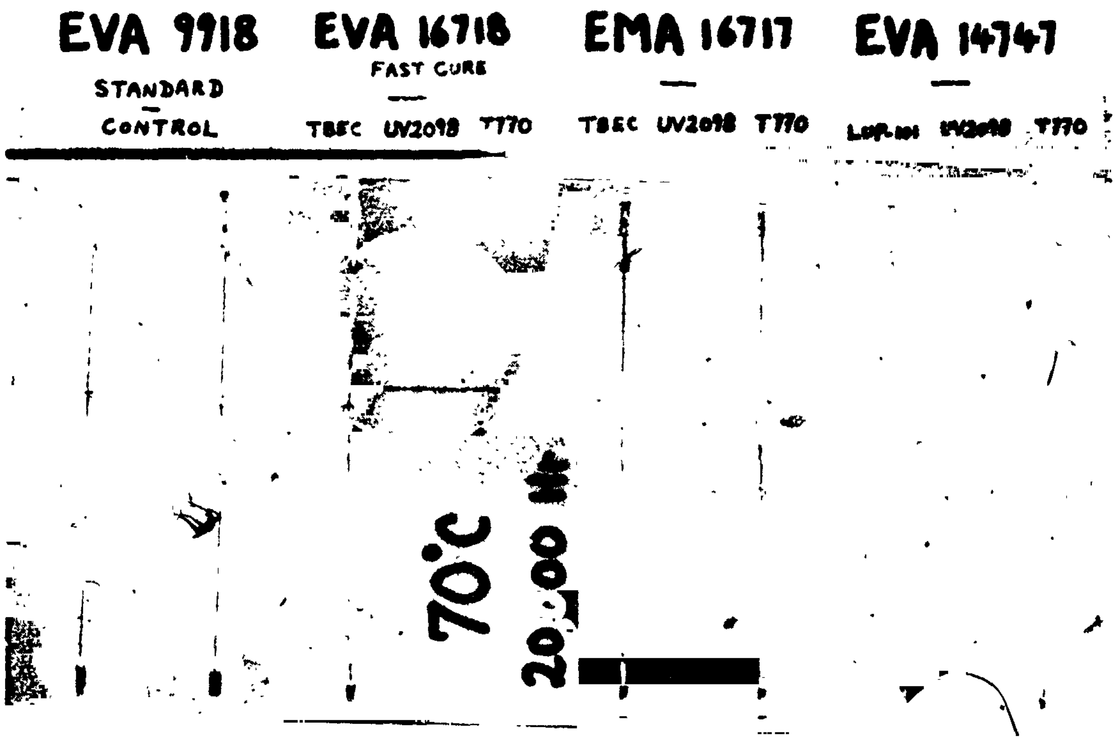


Outdoor Photothermal Aging Reactors (OPTAR), Enfield, Connecticut
(70, 90, and 105°C)



OPTAR/70°C, 20,000 Hours

- SOME COPPER REACTION W/ EVA 9918
- NO OTHER EFFECTS NOTICEABLE



OPTAR/90°C, 20,000 Hours

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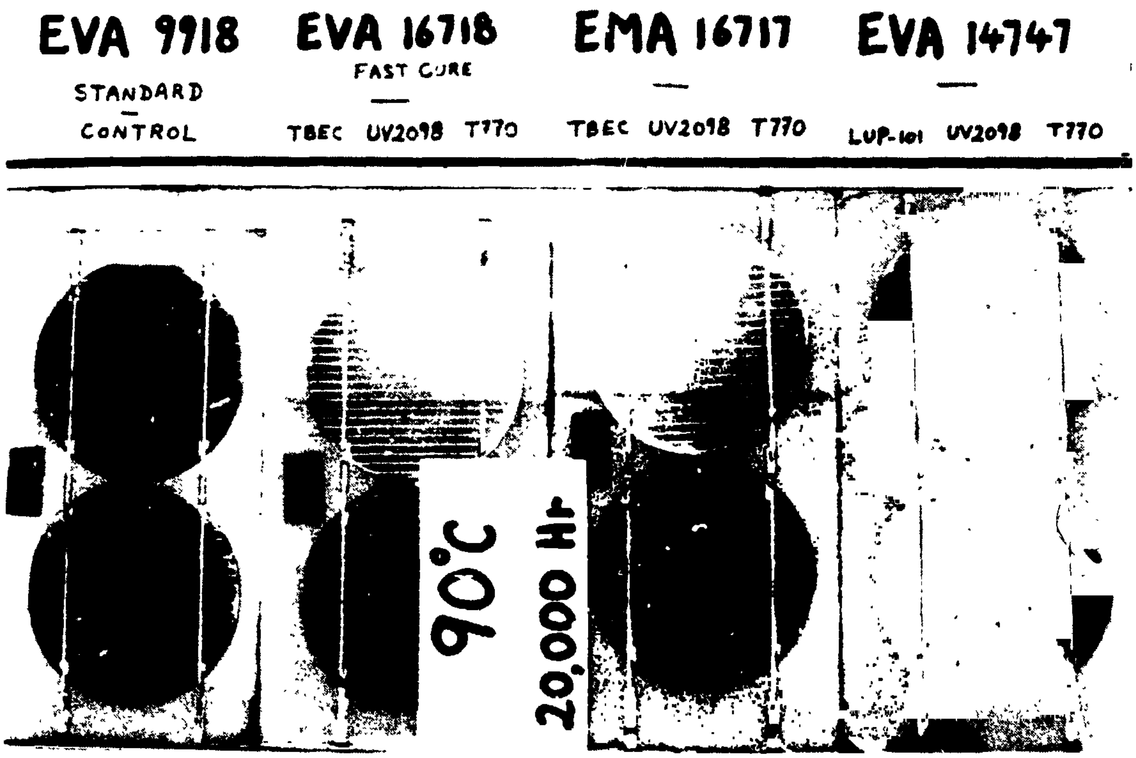
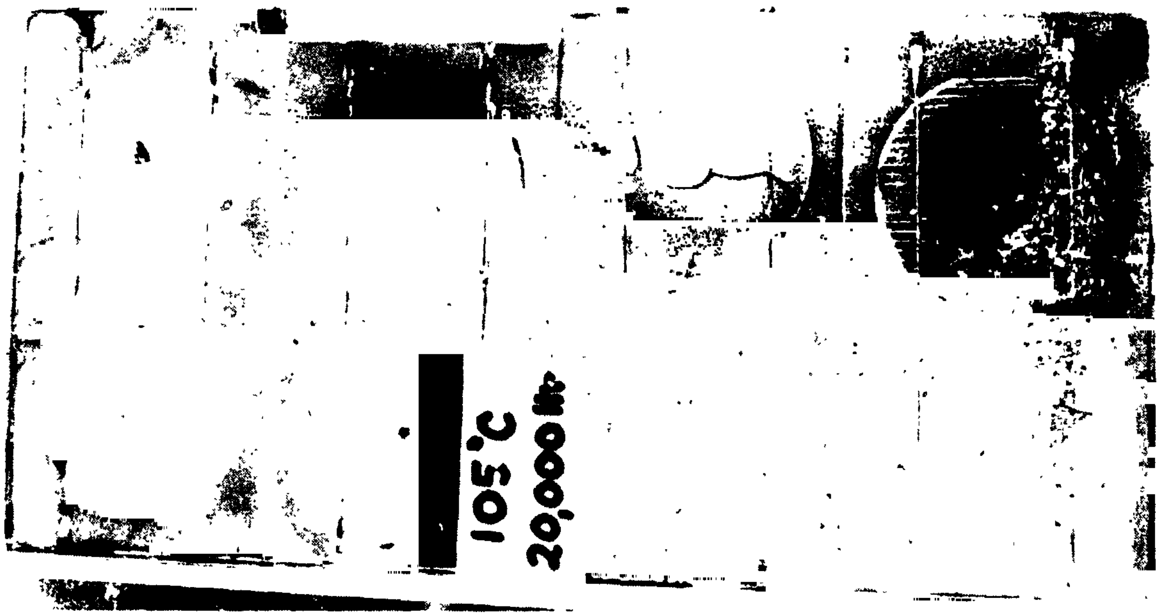
- COPPER REACTION IN LUPERSOL-101 RESINS
- OVERALL CONDITION: VERY GOOD



OPTAR/105°C, 20,000 Hours

- ALL SHOW SEVERE COPPER REACTION
- BEST PERFORMANCE: EVA-ADVANCED STABILIZER TBEC, UV-2098, TINUVIN 770

EVA 9918	EVA 16718	EMA 16717	EVA 14747
STANDARD CONTROL	FAST CUR. — TBEC UV2098 T770	— TBEC UV2098 T770	— LUP-101 UV2098 T770



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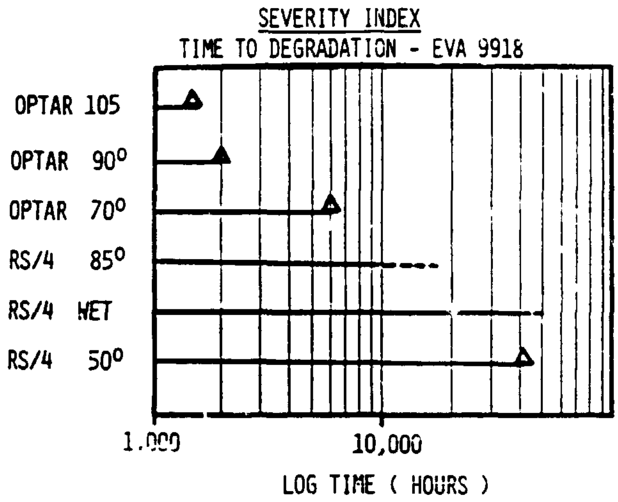
Accelerated Aging: Summary of Investigations



- OPTARS MOST EFFICIENT AGING TECHNIQUE
- MODULES HAVE VERY HIGH ENDURANCE
  NO EFFECT: 20,000 HRS - 70°C / SUNLIGHT
- DEGRADED MODULES SHOW NO POWER LOSS
- EVA 9918 (STANDARD FORMULA) PERFORMS VERY WELL
- OPTIMIZED EVA FORMULATION:

LUPERSOL TBEC	CURING AGENT
CYASORB UV-2098	UV SCREENER
TINUVIN 770	STABILIZER

- RADIOMETER INSTALLED ON OPTAR DEVICES - POSSIBILITY FOR MODELING BASED ON HEAT PLUS LIGHT ???

Adhesion Experiments

STATUS:

- PRIMER FORMULATIONS IDENTIFIED FOR ALMOST ALL INTERFACES IN MODULES
  - POLYMER / METAL
  - POLYMER / INORGANIC
  - POLYMER / ORGANIC

  DR. PLUEDDEMANN - DOW CORNING

  DR. JIM BOERIO - UNIVERSITY OF CINCINNATI
- SELF-PRIMING FORMULATIONS OF EVA (TO GLASS, CELLS) DEVELOPED: AVAILABLE - SPRINGBORN
- NEW PRIMER AVAILABLE - DOW CORNING WITH IMPROVED PROPERTIES - UNDER TEST

Adhesion Diagnostics

- NEW METHOD DEVELOPED
- EVA COMPOUNDED WITH HIGH LOADINGS OF SILANE TREATED GLASS BEADS - RESEMBLES GLASS REINFORCED POLYMER
- EQUILIBRIUM WATER ABSORPTION VALUES MAY PROVIDE NEW METHOD OF EVALUATING ADHESIVE BONDS - INDICATES " DAMAGE " TO BONDS AT THE INTERFACE IS REVERSIBLE UP TO A LIMIT
- DETERMINE DEGRADATION RATES (KINETICS)
- ASSESS SERVICE LIFE
- GENERAL CONCLUSION - BOND DURABILITY - EXCELLENT

Electrical Isolation

- POTTANTS AND COVER FILMS SERVE AS ELECTRICAL INSULATION
- NEED TO KNOW THICKNESS REQUIRED FOR VOLTAGE STANDOFF
- VARIATION WITH TEMPERATURE, ABSORBED WATER ?
- NEED TO KNOW VARIATION DIELECTRIC STRENGTH WITH AGING: LIGHT, HEAT, HUMIDITY, FIELD STRESS

METHOD:

- HV-DC POWER SUPPLY, SYMMETRIC ELECTRODES
- SPECIFIED RATE OF RISE (500 V/SEC)
- PLOT AVERAGE BREAKDOWN VOLTAGE, V_A VS THICKNESS
- STRAIGHT LINE RELATIONSHIP: SLOPE EQUALS " INTRINSIC DIELECTRIC STRENGTH " ' DC)
- MEASUREMENTS TO DATE:
  EVA 9918, DV/DT = 3.48 KV/MIL

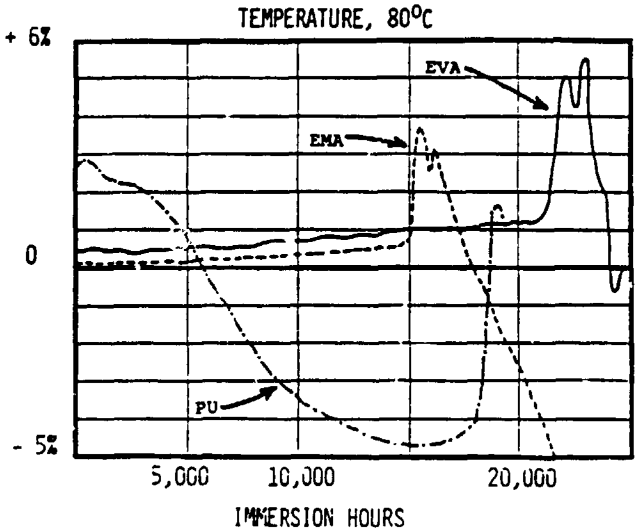
RESULTS TO DATE: EVA A9918

			△
RS/4 (50°C)	4,000 HR	3.24 KV/MIL	93%
RS/4 (85°C)	4,000 HR	1.98 KV/MIL	57%
RS/4 WET	4,000 HR	4.12 KV/MIL	118%
OPTAR 70°C	2,000 HR	2.85 KV/MIL	82%
OPTAR 90°C	2,000 HR	3.14 KV/MIL	90%
OPTAR 105°C	2,000 HR	- - UNTESTABLE - -	

- NEW SPECIMEN GEOMETRY NEEDED - NOW UNDER TEST
- SOME EVIDENCE FOR DECREASE IN DIELECTRIC STRENGTH WITH ACCELERATED AGING
- INCREASE IN STRENGTH WITH WATER EXPOSURE

Hydrolytic Stability

- CANDIDATE POTTANTS - WA⁻ ⁻R IMMERSION AT 40°, 60°, 70°, 80° A.ɪᴅ 90°
- MEASURE CHANGE IN WEIGHT VERSUS TIME



	TIME TO ONSET OF CHANGE, HOURS		
	70°	80°	90°
EVA	?	21,000	14,000
EMA	?	15,000	9,800
PU	------	CONTINUAL	-------

- EVA VERY HYDROLYTICALLY STABLE
- DATA WILL BE USED FOR KINETICS

Anti-Soiling Treatments

SURFACE CHEMISTRY:

- HARD
- SMOOTH
- HYDROPHOBIC
- OLEOPHOBIC
- ION FREE
- LOW SURFACE ENERGY

SURFACE INVESTIGATED:

- SUNADEX GLASS
- TEDLAR (100 BG 30 UT)
- ACRYLAR (ACRYLIC FLIM)

MOST EFFECTIVE TREATMENT:

- E-3820 PERFLUORODECANOIC ACID/ SILANE (DOW CORNING)
- STILL EFFECTIVE AT 56 MONTHS OUTDOOR EXPOSURE
- RESULTS IN IMPROVED POWER OUTPUT OF 1% TO 4% - DEPENDING ON SURFACE
- FLUOROALKYL SILANE CHEMISTRY APPEARS TO BE MOST EFFECTIVE

NEW TREATMENTS:

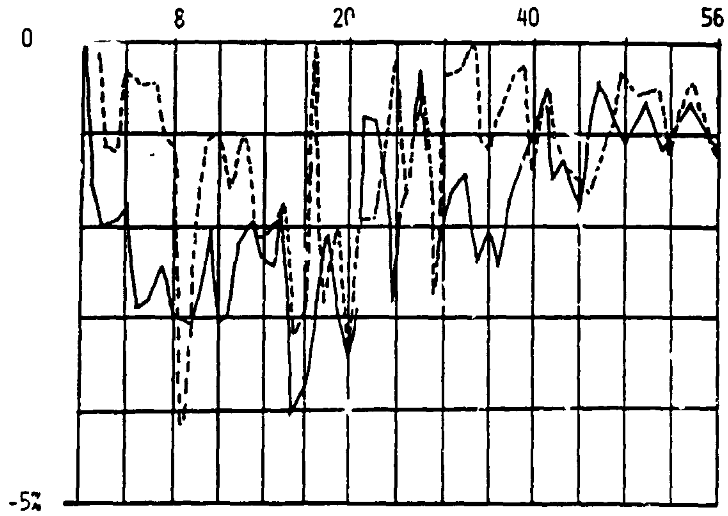
- TWO NEW CANDIDATES FROM DOW CORNING STARTED

Soiling Experiments

FIFTY-SIX MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN I_{sc} WITH STANDARD CELL TREATED
SUNDEX GLASS

56 MONTHS EXPOSURE



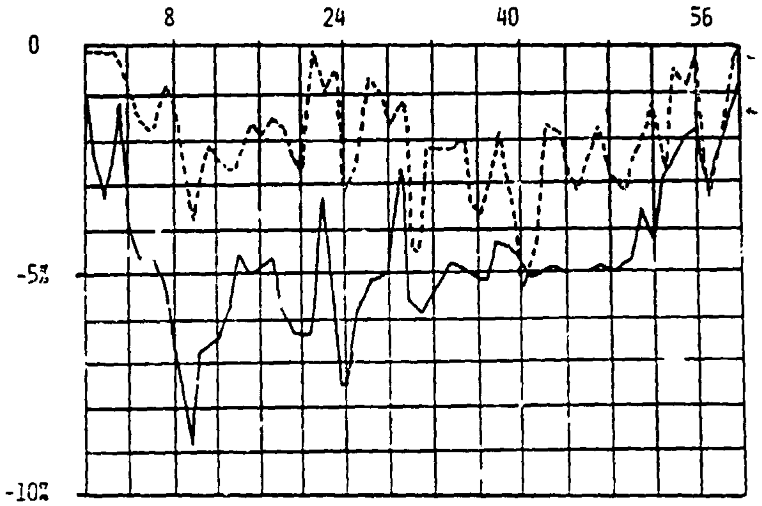
CONTROL, NO TREATMENT
E3820
• ESTIMATED AVERAGE POWER IMPROVEMENT, 1%

Soiling Experiments (Cont'd)

FIFTY-SIX MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN I_{sc} WITH STANDARD CELL TREATED
TEDLAR 100BG30OUT
(SUPPORT ON GLASS)

56 MONTHS EXPOSURE



——— CONTROL, NO TREATMENT
- - - - - E3820

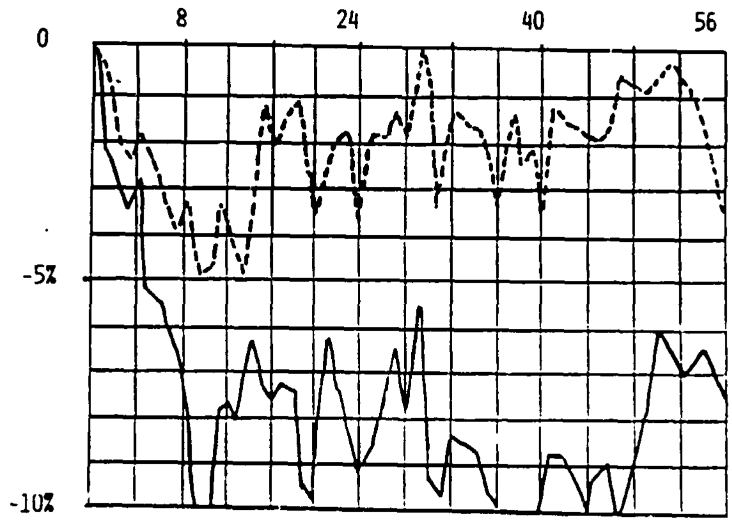
- ESTIMATED AVERAGE POWER IMPROVEMENT, 3.8%

Soiling Experiments (Cont'd)

FIFTY-SIX MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN I_{SC} WITH STANDARD CELL TREATED ACRYLAR
(SUPPORTED ON GLASS)

56 MONTHS EXPOSURE



——— CONTROL, NO TREATMENT
– – – – OZONE + E3820
• ESTIMATED AVERAGE POWER IMPROVEMENT, 3.9%

Process Sensitivity

GOALS:

- UNDERSTAND RELATIONSHIPS BETWEEN ALL MANUFACTURING VARIABLES
- DEFINE FAILURE / ACCEPTABILITY CRITERIA
- STATISTICAL ANALYSIS OF RESULTS
- DEFINE OPTIMUM CONDITIONS
- PREDICT MANUFACTURING YIELD
- PROVIDE DOCUMENTATION TO INDUSTRY

VARIABLES

FORMULATION:

- POTTANT COMPOSITION
- CURING AGENTS
- PRIMERS
- STORAGE CONDITIONS

PROCESSING:

- VACUUM PRESSURE
- TEMPERATURE, ULTIMATE, ^{o}C
- TEMPERATURE, RATE OF RISE, ^{o}C / MIN.
- DWELL TIMES
- RATE OF COOLING

Testing and Performance Criteria

METHOD:
- PREPARE TEST MODULES AND / OR OTHER TEST SPECIMENS WITH CHANGE IN SIGNIFICANT VARIABLE(S)
- DEVELOPED STANDARD TEST SPECIMEN
- DEVELOPED STANDARD TEST PROTOCOL
- COLLECTED UNIFORM DATA SETS
- QUANTITATE THE EFFECTS

COMPONENT	CRITERION	TEST
POTTANT	ADEQUATE CURE	PERCENT GEL THERMAL CREEP
	TRAPPED BUBBLES	VISUAL
	DISCOLORATION	VISUAL
CELLS	BREAKAGE	VISUAL, RESISTANCE
	INTERCONNECT	RESISTANCE
	REGISTRATION	VISUAL
COVER FILMS	TEARS / PUNCTURES	VISUAL
	WARPING / SHRINKAGE	VISUAL
GLASS (SUPERSTRATE)	FRACTURE	VISUAL
ADHESION	BOND STRENGTH	PEEL TEST
	ENDURANCE	WATER SOAK (50°C)

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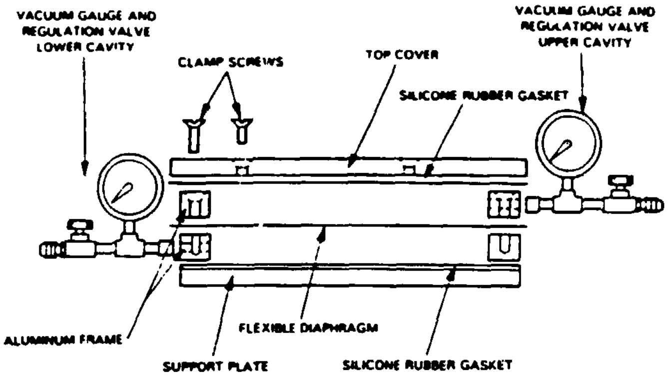
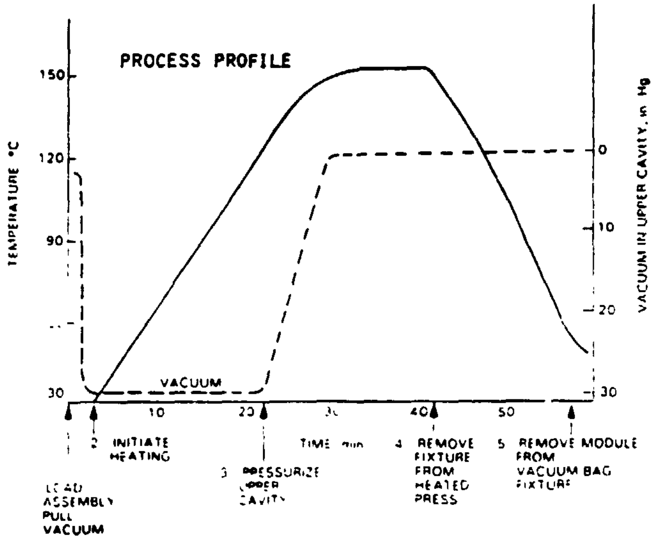
Process Equipment

EXPERIMENTAL LAMINATOR





- MICROPROCESSOR CONTROLLED EXPERIMENTAL LAMINATOR CONSTRUCTED
- STUDIES STARTED ON PROCESSING PROFILES
  - RATE OF HEATING (HOW SLOW, HOW FAST ?)
  - VACUUM TIMING
  - RATE OF COOLING

Process Sensitivity: Observations and Recommendations

FORMULATION VARIABLES

- EVA FORMULATIONS RELATIVELY INSENSITIVE TO QUANTITY OF PEROXIDE BUT VERY SENSITIVE TO AIR EXPOSURE - EVAPORATION
- EVA WITH LUPERSOL - TBEC MUCH LESS SENSITIVE
- UNWRAP / CUT EVA JUST BEFORE MODULE MANUFACTURING - LIMIT AIR EXPOSURE
- SELF-PRIMING GRADE WORKS WELL

PROCESS VARIABLES

- UPPER AND LOWER LIMITS DETERMINED:
  - ULTIMATE TEMPERATURE
  - RATE OF RISE - TEMPERATURE
  - BACKPRESSURE TIMING
- DOMINANT FAILURE : ADHESION (POTTANT / GLASS)
  - BOUNDS THE NARROWEST PROCESSING " WINDOW "
- EVA WITH LUPERSOL-TBEC HAS WIDER WINDOW THAN EVA 9918
  - STORAGE : MORE STABLE TO EXPOSURE
  - PROCESSING : WIDER RANGE OF CONDITIONS
- INDUSTRIAL " TROUBLE SHOOTING GUIDE " PREPARED

Thin-Film Encapsulation

(AMORPHOUS PHOTOVOLTAICS)

TYPES:
- SUPERSTRATE - ON GLASS
- SUBSTRATE - ON STAINLESS STEEL

FAILURE MECHANISMS:

CORROSION , BREAKAGE (GLASS) , ABRASION, ELECTRICAL SHORTING, OTHERS ? ? ?

Encapsulation Requirements (Anticipated)

COMPONENT	PROPERTY
OUTER COVER	• INHERENTLY WEATHERABLE • ABRASION / CUT RESISTANT
BACK COVER	• WHITE (EMISSIVE) • WEATHER RESISTANT
POTTANT	• PROCESSABLE <100°C • CURABLE - CREEP RESISTANT • LOW WATER ABSORPTION • HIGH OPTICAL TRANSMISSION
DURABLE BONDING	• ALL INTERFACES • LONG SERVICE LIFE • LOW COST

Manufacture/Process

- FAST
- AUTOMA.ABLE
- INEXPENSIVE

Thin-Film Encapsulation: Candidate Materials and Processes

BACK COVERS
- WHITE TEDLAR

OUTER COVERS
- FLUOROPOLYMERS BEST CHOICE
- FEP CURRENTLY FAVORED DUE TO HIGH TRANSPARENCY AND OUT-STANDING WEATHERABILITY

FILM	REF. INDEX	% T	COST $/FT2/MIL
FEP	1.34	93.6	0.10

POTTANTS: CONDUCTING INVESTIGATIONS

MATERIAL CLASS	MANUFACTURER	$/LB
ETHYLENE/VINYL ACETATE	DU PONT, USI	.60 - .80
ETHYLENE/ACRYLIC	DOW, GULF	.80 - 1.00
IONOMER	DU PONT	1.08 - 1.60
ALIPHATIC URETHANE	UPJOHN	[illegible] - 2.50
HOT MELT ADHESIVES (HYDROCARBON, POLYAMIDE POLYETHER, ACRYLIC)	MANY	.80 - 2.50

CURE METHOD:
- MOISTURE CURE (MODIFIED CHEMISTRY)
- PEROXIDE DECOMPOSITION (HEAT)
- UV CURE (PHOTOINITIATION)

- MOISTURE CURABLE SELF - PRIMING POTTANT UNDER DEVELOPMENT . SILANE / ACRYLIC CHEMISTRY

ENCAPSULATION METHOD:
- FILM LAMINATION: EXTRUDE THE POTTANT ON AN OUTER COVER FILM AS A CARRIER, USE COMBINATION FOR LAMINATION.

Conclusions

ACCELERATED AGING:

- " OPTAR " METHOD BEST AGING TECHNIQUE DISCOVERED SO ARE
- MODELING / LIFE PREDICTION ENCOURAGING
  - 70° & 90°C VERY GOOD CONDITION
  - COPPER REACTIONS NOT AS SEVERE AS ANTICIPATED - EXCEPT AT 105°C
  - LUPERSOL - TBEC CURED FORMULATIONS APPEAR MORE STABLE
  - BEST STABILIZERS : UV-2098 SCREENER, TINUVIN 770 (BOTH CYANAMIDE)
  - MODULE PERFORMANCE - EXCELLENT (OPTAR 90°C - 20,000 HR - NO CHANGE)

ADHESION:

- NEW TEST METHOD FOR PRIMER EVALUATION AND BOND DURABILITY
- CAN DEMONSTRATE BOND RECOVERY & LIMIT OF REVERSIBILITY
- SELF-PRIMING EVA WORKS WELL

ELECTRICAL ISOLATION:

- INTRINSIC DIELECTRIC TEST METHOD DEVELOPED
- SOME EVIDENCE OF DECREASE IN DIELECTRIC STRENGTH WITH ACCELERATED AGING

Conclusions (Cont'd)

HYDROLYTIC STABILITY:

- EVA APPEARS EXCELLENT

PROCESS SENSITIVITY:

- DOMINANT PROCESS FAILURE MODE : ADHESION
- EVA STORAGE ESSENTIAL
- LUPERSOL TBEC FORMULATIONS - WIDER PROCESS LATITUDE, BETTER STORAGE STABILITY

SOILING:

- TREATMENTS STILL EFFECTIVE AFTER 56 MONTHS

THIN-FILM PV:

- CANDIDATES BEING SELECTED / DEVELOPED